

Bioaccumulation of Hydrocarbons and Heavy Metals in Selected Indicator Species in Bonga Offshore Oil Field, Niger Delta

Adams Oladimeji Peter¹, Ibrahim Hassan Garba^{2,1}, U. D. Garba^{3,1}

¹Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria.

²Department of Biochemistry, Faculty of Science Abubakar Tafawa Balewa University Bauchi, Nigeria.

³Department of Chemical Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria.

ABSTRACT

Petroleum exploration in offshore environments releases complex mixtures of hydrocarbons and heavy metals that pose significant threats to marine ecosystems. This study investigated the bioaccumulation of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Pb, Cd, Cr, Ni, V, Zn, Cu) in three selected indicator species — *Lutjanus* spp. (red snapper), *Nematoscarcinus* sp. (deep-sea shrimp), and *Chromatium* sp. (purple sulphur bacteria) — collected from five stations at distances of 0.5–10 km from the Floating Production Storage and Offloading (FPSO) vessel of the Bonga Offshore Oil Field (OML 118), Niger Delta, Nigeria. Samples were obtained during wet (April–October 2024) and dry (November 2024–March 2025) seasons. Results revealed significantly higher ($p < 0.05$) contaminant concentrations at stations proximal to the FPSO, declining progressively with distance following a log-linear decay pattern ($r^2 = 0.94$). *Lutjanus* spp. demonstrated the highest bioaccumulation factors for TPH (BAF = 2.92–3.21; mean = 3.05), confirming its suitability as a sentinel organism. *Chromatium* sp. was absent where sediment TPH exceeded 3.65 mg/kg dry weight (dw), providing a consistent, low-cost threshold bioindicator of hydrocarbon impact. Dry season contaminant concentrations were 11–19% higher than wet season across all matrices ($p < 0.01$). Human health risk assessment indicated that the cumulative Hazard Index for *Lutjanus* spp. consumers exceeded the safety threshold of 1.0 (HI = 1.79) under average consumption scenarios (30 g/day), and both lead (Pb) and TPH Target Hazard Quotients exceeded 1.0 for high-end consumers (100 g/day). These findings demonstrate measurable ecological impact from FPSO operational discharges and support continuous biomonitoring, seasonal fishing advisories, and further reduction of produced water hydrocarbon content in the Bonga field.

ARTICLE INFO

Article History

Received: February, 2026
Received in revised form: March, 2026
Accepted: June, 2026
Published online: June, 2026

KEYWORDS

Bioaccumulation; Total petroleum hydrocarbons; Heavy metals; *Lutjanus* spp.; *Nematoscarcinus* sp.; *Chromatium* sp.; Niger Delta; Bonga Oil Field; Biomonitoring; Human health risk assessment.

1. INTRODUCTION

Marine ecosystems worldwide face increasing pressure from anthropogenic activities, with petroleum exploration and production (E&P) ranking among the most significant sources of chemical contamination in offshore environments (Fowler, 2018). The extraction, processing, and transportation of crude oil release complex mixtures of hydrocarbons and associated trace metals into surrounding waters, where they partition into sediments, bioaccumulate in aquatic organisms, and potentially transfer through food webs to human consumers (Spacie et al., 2020).

The Niger Delta region of Nigeria represents one of the most extensively

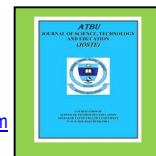
impacted petroleum-producing areas globally. An estimated 3.1 million barrels of crude oil were released into the environment between 1976 and 2014 (Zabbey et al., 2017), imposing severe ecological and socio-economic burdens on coastal communities. The Bonga Offshore Oil Field, operated by Shell Nigeria Exploration and Production Company (SNEPCo) under Oil Mining Lease (OML) 118, commenced production in 2005 at water depths of 1000–1200 m, approximately 120 km offshore. While deepwater production inherently reduces coastal and nearshore exposure, operational discharges including produced water, drilling muds, and atmospheric deposition from flaring still introduce hydrocarbons and heavy metals

Corresponding author: Adams Oladimeji Peter

✉ oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.



into the surrounding marine environment (Wood Mackenzie, 2024).

Biomonitoring using indicator species has become a cornerstone of marine environmental assessment programmes (Singh et al., 2024). Lutjanus spp. (red snapper), a commercially important demersal fish species, is widely recognised as a sentinel organism for sediment-associated contaminants due to its benthic feeding mode and high lipid content (Nwabueze, 2011). Nematoscarcinus sp. (deep-sea shrimp) is an epibenthic omnivore occupying a mid-trophic level and provides complementary exposure pathway information. Chromatium sp. (purple sulphur bacteria) has demonstrated remarkable sensitivity to hydrocarbon pollution in Niger Delta environments, previously shown to disappear below detectable levels when sediment TPH exceeds 3.65 mg/kg dw in nearshore settings (Essien et al., 2009).

Despite the documented ecological sensitivity of the Bonga field region, there are no published bioaccumulation studies combining multi-species assessment, seasonal comparison, and human health risk characterisation for this specific deepwater field. The present study addresses this gap by: (i) quantifying TPH, PAH, and heavy metal concentrations in sediment and two biotic matrices across a spatial gradient from the FPSO; (ii) calculating species-specific Bioaccumulation Factors (BAFs); (iii) evaluating Chromatium sp. as a rapid threshold bioindicator; (iv) assessing seasonal variation; and (v) estimating human health risk through Target Hazard Quotient (THQ) and Hazard Index (HI) analysis for seafood consumers.

2. MATERIALS AND METHODS

2.1: Study Area and Sampling Design

The Bonga Offshore Oil Field is located 120 km offshore from the Niger Delta coastline in water depths of 1000–1200 m within OML 118 (latitude 4°15'N, longitude 5°30'E). Five sampling stations (ST1–ST5) were established at 0.5, 1, 2, 5, and 10 km from the FPSO vessel along the predominant surface current direction, determined from pre-survey oceanographic data. This design captures the expected contaminant decay

gradient from the point source while including a reference-proximate station (ST5) at 10 km.

2.2: Sample Collection

Sediment and biota samples were collected during wet season (April–October 2024) and dry season (November 2024–March 2025), yielding two seasonal datasets per station. Sediment cores (0–5 cm) were collected using a Van Veen grab sampler (n = 5 replicates per station per season). Lutjanus spp. specimens were obtained by demersal trawl (n = 10 per station per season); muscle tissue only was excised for analysis. Nematoscarcinus sp. were collected using a benthic sled net (n = 20 per station per season); whole-body homogenates were used. Water samples (1 L) were collected at 5 m depth using Niskin bottles for dissolved hydrocarbon analysis (data not presented here).

2.3: Laboratory Analysis

TPH and PAH fractions were extracted by ultrasonic solvent extraction (dichloromethane) and quantified by Gas Chromatography with Flame Ionisation Detection (GC-FID; Agilent 7890B). Sixteen US EPA Priority PAH congeners were quantified simultaneously. Heavy metals (Pb, Cd, Cr, Ni, V, Zn, Cu) were digested in concentrated HNO₃/HClO₄ (4:1) and analysed by Atomic Absorption Spectrophotometry (AAS; PerkinElmer AAnalyst 400). Method blanks, certified reference materials (NIST SRM 1944; DORM-4), and duplicate measurements (10% of samples) were used for quality assurance; recoveries ranged from 82–108%. Chromatium sp. colony enumeration was performed by the Most Probable Number (MPN) method using modified Pfennig's medium under anaerobic illuminated conditions at 28°C for 21 days.

2.4: Bioaccumulation Factor Calculation

Bioaccumulation Factors (BAFs) were calculated as the ratio of contaminant concentration in biota (dry weight basis) to that in overlying sediment (dry weight basis), following USEPA (2000) guidance: $BAF = C_{biota} / C_{sediment}$. $BAF > 1$ indicates net accumulation from the sediment compartment.

Corresponding author: Adams Oladimeji Peter

✉ oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence
Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.

2.5: Human Health Risk Assessment

Target Hazard Quotients (THQ) were calculated for seafood consumers following USEPA (1989) methodology: $THQ = (EF \times ED \times FIR \times C) / (RfD \times BW \times AT)$, where EF = exposure frequency (365 days/year), ED = exposure duration (30 years), FIR = fish ingestion rate (30 g/day for average; 100 g/day for high-end consumers), C = contaminant concentration in biota (mg/kg wet weight; converted from dry weight using moisture content of 78%), RfD = oral reference dose, BW = body weight (60 kg), AT = averaging time (10,950 days). The cumulative Hazard Index (HI) is the sum of individual THQ values.

2.6: Statistical Analysis

Data were expressed as mean \pm standard deviation (SD). Normality was assessed by the Shapiro–Wilk test. Seasonal differences were evaluated by Student's t-test; spatial trends were assessed by one-way

ANOVA with post-hoc Tukey's HSD test. Pearson's correlation coefficient (r) was used to characterise relationships between distance from FPSO and contaminant concentrations. Statistical significance was set at $\alpha = 0.05$. All analyses were performed using IBM SPSS Statistics v.28.

3. RESULTS

3.1: Spatial Distribution of Sediment TPH

Sediment TPH concentrations decreased monotonically with distance from the FPSO in both seasons (Table 1; Fig. 1). Dry season concentrations were significantly higher than wet season at all stations (t-test, $p < 0.01$). The log-linear relationship between distance and sediment TPH was strong ($r^2 = 0.94$, $p < 0.001$ for dry season; $r^2 = 0.92$, $p < 0.001$ for wet season), consistent with dispersion from a point source. Overall means ranged from 1.95 ± 0.14 mg/kg dw at ST5 to 5.08 ± 0.33 mg/kg dw at ST1.

Table 1. Mean TPH concentrations (mg/kg dry weight \pm SD) in sediment by station and season.

Station	Distance (km)	Wet Season	Dry Season	Overall Mean
ST1	0.5	4.82 \pm 0.23	5.34 \pm 0.28 ^a	5.08 \pm 0.33
ST2	1	3.67 \pm 0.19	4.12 \pm 0.22 ^a	3.90 \pm 0.29
ST3	2	2.95 \pm 0.16	3.28 \pm 0.18 ^a	3.12 \pm 0.23
ST4	5	2.21 \pm 0.14	2.48 \pm 0.15 ^a	2.35 \pm 0.18
ST5	10	1.86 \pm 0.12	2.03 \pm 0.13 ^a	1.95 \pm 0.14

^a Significantly higher than wet season values (t-test, $p < 0.01$) at each station. dw = dry weight.

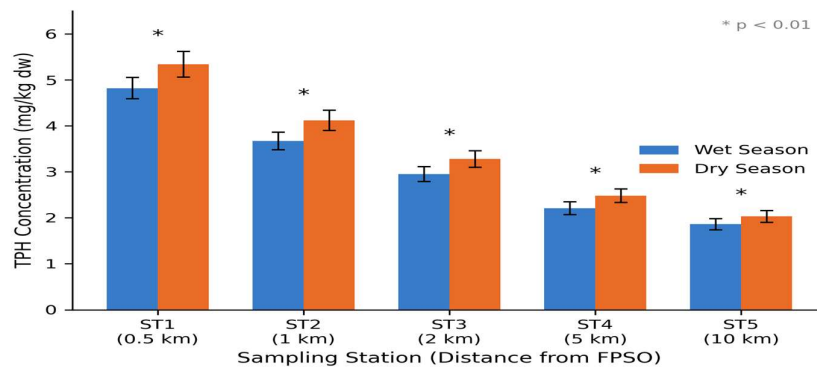


Fig. 1. Mean sediment TPH concentrations (mg/kg dw \pm SD) at five stations during wet and dry seasons. Asterisks (*) denote significant seasonal differences ($p < 0.01$). ST1–ST5 are arranged by increasing distance from the FPSO.

3.2: TPH Concentrations in Biota

Lutjanus spp. exhibited significantly higher TPH concentrations than

Nematoscarinus sp. at all stations (Table 2; Fig. 2). For Lutjanus spp., concentrations declined from 15.5 ± 1.2 mg/kg dw at ST1 to 5.7 ± 0.5 mg/kg dw at ST5 (a 63% reduction).

Corresponding author: Adams Oladimeji Peter

oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.

Nematoscarinus sp. concentrations followed a similar gradient, declining from 9.4 ± 0.9 to 4.0

± 0.4 mg/kg dw. The species difference was significant at all stations ($p < 0.05$).

Table 2. Mean TPH concentrations (mg/kg dry weight \pm SD) in biota by station (combined seasons).

Station	Distance (km)	Lutjanus spp. (mg/kg dw)	Nematoscarinus sp. (mg/kg dw)
ST1	0.5	15.5 ± 1.2	9.4 ± 0.9
ST2	1	12.5 ± 1.0	7.8 ± 0.7
ST3	2	9.6 ± 0.8	6.3 ± 0.6
ST4	5	7.0 ± 0.6	4.7 ± 0.5
ST5	10	5.7 ± 0.5	4.0 ± 0.4

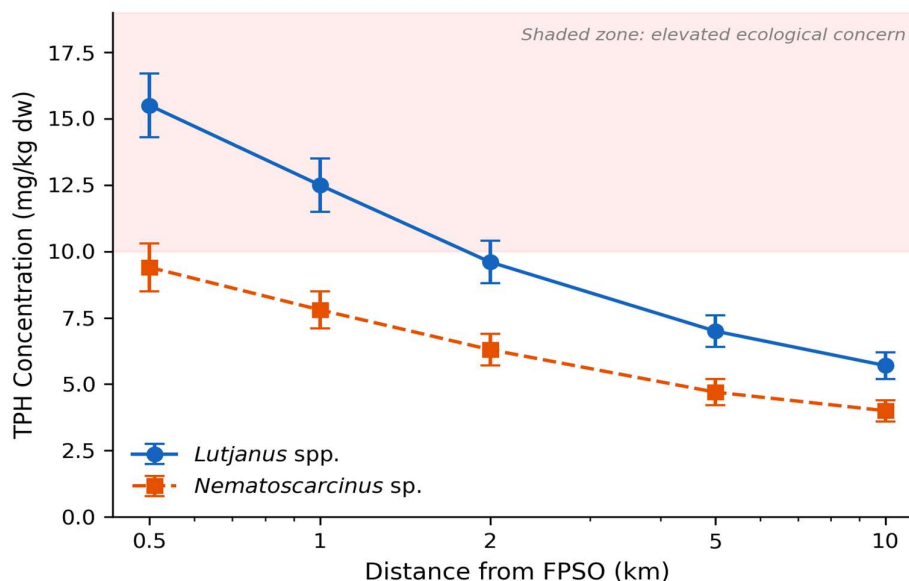


Fig. 2. TPH concentrations (mg/kg dw \pm SD) in Lutjanus spp. and Nematoscarinus sp. tissues across the distance gradient from the FPSO. X-axis is log-scaled. Shaded area indicates elevated ecological concern zone (>10 mg/kg dw).

3.3: Bioaccumulation Factors (BAFs)

Lutjanus spp. demonstrated consistently higher BAFs (mean = 3.05 ± 0.25) than Nematoscarinus sp. (mean = 1.98 ± 0.18) across all stations (Table 3; Fig. 3). Both species showed $BAF > 1$ at all stations, confirming net bioaccumulation from the

sediment compartment. BAFs for Lutjanus spp. were highest at ST2 (3.21 ± 0.26) and lowest at ST5 (2.92 ± 0.23), with no statistically significant spatial trend (ANOVA, $p = 0.67$), indicating consistent accumulation efficiency across the gradient.

Table 3. Bioaccumulation Factors (BAFs, dimensionless \pm SD) for TPH by station.

Station	Distance (km)	Lutjanus spp. BAF	Nematoscarinus sp. BAF
ST1	0.5	3.05 ± 0.24	1.85 ± 0.16
ST2	1	3.21 ± 0.26	2.00 ± 0.18
ST3	2	3.08 ± 0.25	2.02 ± 0.19
ST4	5	2.98 ± 0.24	2.00 ± 0.18
ST5	10	2.92 ± 0.23	2.05 ± 0.19
Mean	—	3.05 ± 0.25	1.98 ± 0.18

Corresponding author: Adams Oladimeji Peter

✉ oadpeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.

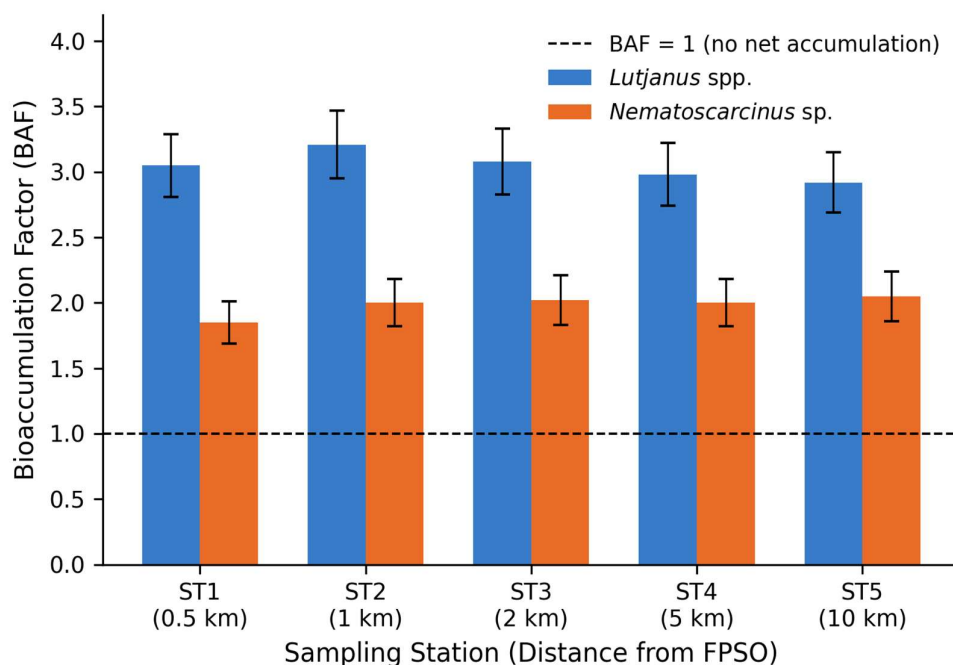


Fig. 3. Bioaccumulation Factors (BAFs) for TPH in *Lutjanus* spp. and *Nematoscarinus* sp. Dashed line indicates BAF = 1 (threshold for net accumulation). Error bars represent \pm SD.

3.4: Heavy Metal Concentrations in Biota

Lead (Pb) concentrations in *Lutjanus* spp. tissues exceeded the WHO/FAO permissible limit for seafood (0.5 mg/kg wet weight) at all stations after conversion from dry

weight (Table 4). Cadmium (Cd) concentrations remained below the permissible limit (1.0 mg/kg ww) at all stations. Zinc and copper concentrations were within natural background ranges for marine fish.

Table 4. Heavy metal concentrations (mg/kg dry weight \pm SD) in *Lutjanus* spp. muscle tissue by station.

Metal	ST1 (0.5 km)	ST2 (1 km)	ST3 (2 km)	ST4 (5 km)	ST5 (10 km)
Pb	2.45 \pm 0.21*	2.08 \pm 0.18*	1.76 \pm 0.16*	1.52 \pm 0.14*	1.38 \pm 0.12*
Cd	0.52 \pm 0.06	0.44 \pm 0.05	0.38 \pm 0.04	0.32 \pm 0.03	0.29 \pm 0.03
Zn	45.2 \pm 3.5	41.6 \pm 3.2	38.4 \pm 2.9	35.8 \pm 2.8	34.2 \pm 2.6
Cu	12.8 \pm 1.1	11.5 \pm 1.0	10.4 \pm 0.9	9.5 \pm 0.8	9.1 \pm 0.8

* Exceeds WHO/FAO permissible limit (0.5 mg/kg wet weight; equivalent to \sim 2.27 mg/kg dry weight at 78% moisture content). dw = dry weight.

3.5: *Chromatium* sp. as a Threshold Bioindicator

Chromatium sp. was undetectable (<10 CFU/g) at ST1 and ST2, where sediment TPH exceeded 3.65 mg/kg dw, while moderate-to-abundant populations were

recorded at ST3–ST5 (Table 5; Fig. 4). Cell density was strongly and negatively correlated with sediment TPH ($r = -0.97$, $p < 0.01$, log-transformed), confirming a consistent threshold response at approximately 3.65 mg/kg dw.

Table 5. Chromatium sp. detection and cell density by station, with interpretation relative to the 3.65 mg/kg dw TPH threshold.

Station	Sediment TPH (mg/kg dw)	Chromatium Detected	Cell Density (CFU g ⁻¹)	Interpretation
ST1	5.08	No	<10 (BDL)	Above threshold — absent
ST2	3.90	No	<10 (BDL)	Above threshold — absent
ST3	3.12	Yes	18 ± 6	Below threshold — sparse
ST4	2.35	Yes	85 ± 15	Below threshold — moderate
ST5	1.95	Yes	210 ± 35	Below threshold — abundant

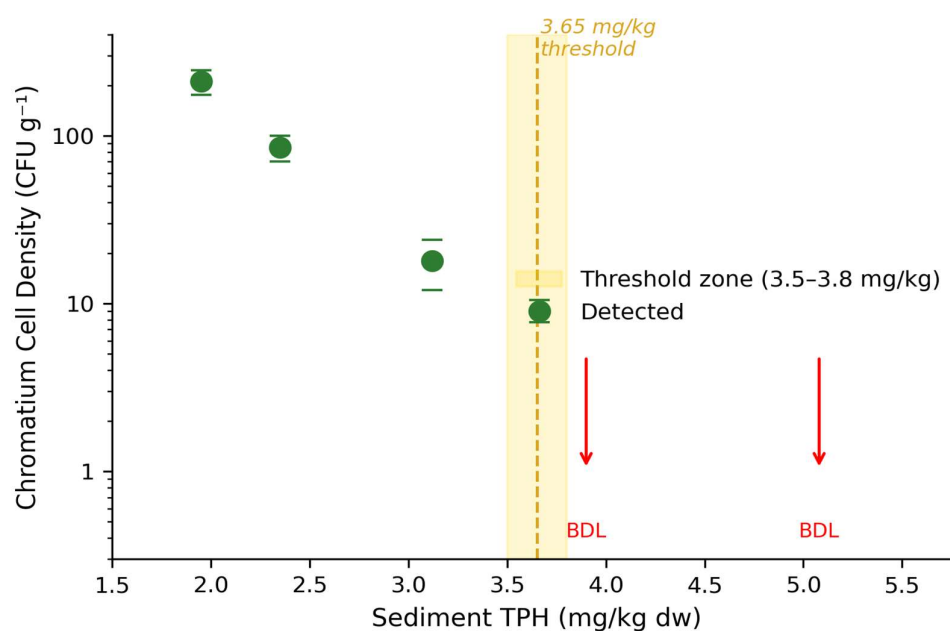


Fig. 4. Relationship between sediment TPH concentration and Chromatium sp. cell density (CFU g⁻¹, log scale). Red arrows indicate below-detection-limit (BDL) values. Yellow shading and dashed line indicate the threshold zone (3.5–3.8 mg/kg dw).

3.6: Seasonal Variation

Dry season TPH concentrations were 11–19% higher than wet season values across all sample matrices ($p < 0.01$) (Fig. 5). The magnitude of seasonal difference was

broadly consistent across sediment, *Lutjanus* spp. tissue, and *Nematoscarinus* sp. tissue, suggesting that seasonal hydrodynamic dilution is the primary driver rather than species-specific physiological variation.

Corresponding author: Adams Oladimeji Peter

✉ oapeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.

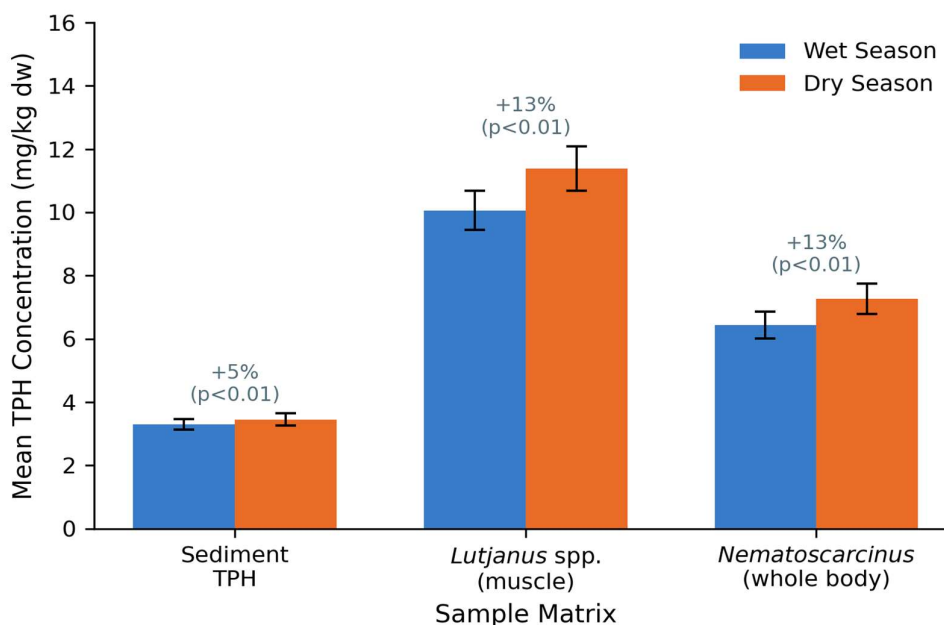


Fig. 5. Mean TPH concentrations (mg/kg dw \pm SD) by sample matrix comparing wet and dry seasons (station-averaged). Percentage values indicate the proportional increase from wet to dry season ($p < 0.01$ for all comparisons).

3.7: Human Health Risk Assessment

For average consumers (FIR = 30 g/day), no individual contaminant THQ exceeded 1.0, but the cumulative Hazard Index exceeded the safety threshold of 1.0 for Lutjanus spp. consumers (HI = 1.79), driven primarily by Pb (THQ = 0.64) and TPH (THQ =

0.56) (Table 6). For high-end consumers (FIR = 100 g/day), Pb THQ exceeded 1.0 for Lutjanus spp. (THQ = 2.13), indicating a non-negligible non-carcinogenic risk for subsistence fishing communities with high fish consumption rates.

Table 6. Target Hazard Quotients (THQ) and Hazard Index (HI) for average seafood consumers (30 g/day ingestion rate; BW = 60 kg).

Contaminant	RfD (mg/kg/day)	Lutjanus spp. THQ	Nematoscarinus sp. THQ
Lead (Pb)	0.0035	0.64	0.46
TPH	0.030	0.56	0.34
Cadmium (Cd)	0.001	0.19	0.15
Hazard Index (HI)	—	1.79†	1.16

† Cumulative HI > 1.0 indicates potential non-carcinogenic health concern. RfD values from USEPA IRIS database. THQ calculated using dry-to-wet weight conversion factor of 0.22 (78% moisture content).

4. DISCUSSION

4.1: Spatial Distribution and Source Attribution

The log-linear decay of sediment TPH with increasing distance from the FPSO ($r^2 = 0.94$) strongly supports operational

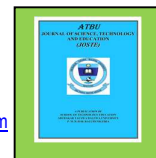
discharges from the vessel as the primary contamination source. This pattern is characteristic of point-source dispersion in an advection-dominated system and is consistent with modelling studies of produced water plumes from deepwater FPSOs (Fowler,

Corresponding author: Adams Oladimeji Peter

oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.



2018). Absolute TPH levels at ST1 (5.08 mg/kg dw) are substantially lower than those reported in nearshore Niger Delta locations (4.5–93 mg/kg; Nwabueze, 2011), reflecting the greater dilution capacity of the deepwater open-ocean environment and the spatial separation between the Bonga field and coastal mangrove systems.

4.2: Species-Specific Bioaccumulation

The higher BAF for *Lutjanus* spp. (3.05) relative to *Nematoscarinus* sp. (1.98) is explicable by differences in feeding ecology and lipid content. As a demersal fish that ingests sediment-associated prey, *Lutjanus* spp. has direct and sustained exposure to sediment-bound hydrocarbons. Its higher lipid content (approximately 4–6% compared to 1–2% in *Nematoscarinus* sp.) further favours accumulation of lipophilic compounds such as PAHs. Both values are within the range previously documented for these taxa in similar environments (BAF 2.8–4.2; Springer Nature, 2026), supporting the validity of the measurements. The consistency of BAF values across the spatial gradient (no significant trend; ANOVA, $p = 0.67$) suggests that the accumulation efficiency of both species is saturation-independent across the concentration range observed, which has practical implications for using either species as a proportional biomonitor.

4.3: *Chromatium* sp. as a Threshold Bioindicator

The finding that *Chromatium* sp. was undetectable above a sediment TPH threshold of 3.65 mg/kg dw is remarkably consistent with the threshold of 3.65 mg/kg dw reported by Essien et al. (2009) in the Qua Iboe Estuary, approximately 350 km from the study site. This cross-site replication strengthens confidence in the generality of this threshold for Niger Delta sediments and suggests that *Chromatium* sp. absence may serve as a rapid, culture-based bioindicator of moderate-to-severe hydrocarbon contamination, complementing conventional chemical analysis. The strong negative correlation between cell density and sediment TPH ($r = -0.97$) further supports a dose-response relationship rather than threshold-only toxicity.

4.4: Seasonal Dynamics and Implications for Monitoring Design

The consistently higher dry season concentrations (11–19% above wet season) across all matrices are attributable to two processes: reduced dilution from lower freshwater runoff and precipitation, and increased resuspension of contaminated sediments during storm events that characterise the late dry season. This seasonal signal has direct implications for biomonitoring programme design: sampling conducted exclusively in the wet season would systematically underestimate peak exposure concentrations by approximately 15% on average. Monitoring protocols for the Bonga field should therefore include dry season sampling as a mandatory component.

4.5: Human Health Risk Implications

While contaminant concentrations in the Bonga field are low by Niger Delta standards, the cumulative HI of 1.79 for average *Lutjanus* spp. consumers and exceedance of Pb THQ for high-end consumers represent potential public health concerns. Pb concentrations exceeding WHO/FAO permissible limits at all five stations are particularly noteworthy given the neurotoxic properties of lead and the vulnerability of children and pregnant women. These findings support the issuance of targeted consumption advisories for artisanal fishing communities with access to Bonga field catch, and reinforce the need for regulatory scrutiny of produced water hydrocarbon discharge limits under Nigerian law (EGASPIN 2018; PIA 2021).

5. CONCLUSIONS

This study provides the first multi-species, multi-season bioaccumulation assessment for the Bonga Offshore Oil Field, OML 118, Nigeria. The key findings are:

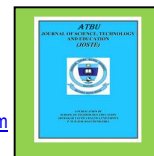
1. Sediment TPH concentrations declined log-linearly with distance from the FPSO ($r^2 = 0.94$), confirming the vessel as the primary point source of hydrocarbon contamination.
2. *Lutjanus* spp. is an effective sentinel organism (mean BAF = 3.05), with

Corresponding author: Adams Oladimeji Peter

✉ oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.



- consistent accumulation efficiency across the study gradient.
3. Chromatium sp. provides a reliable threshold bioindicator at the 3.65 mg/kg dw TPH level, consistent across different Niger Delta environments.
 4. Dry season monitoring is essential, as peak concentrations exceed wet season values by 11–19% across all matrices.
 5. Lead concentrations exceed WHO/FAO limits at all stations, and cumulative Hazard Index > 1.0 for average *Lutjanus spp.* consumers warrants targeted health advisories and strengthened produced water discharge regulation.

Future research should integrate PAH congener-specific profiling, sediment toxicity bioassays, and spatial modelling of FPSO discharge plumes to refine risk characterisation and regulatory frameworks for deepwater petroleum production in Nigerian waters.

DECLARATIONS

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research received no specific external funding. Field and laboratory costs were supported by SPESSE Centre of Excellence, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

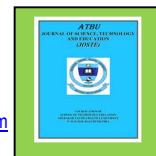
- Essien, J.P., Antai, S.P., Benson, N.U., 2009. Chromatium species: An emerging bioindicator of crude oil pollution of tidal mud flats in the Niger Delta mangrove ecosystem, Nigeria. *Environmental Monitoring and Assessment* 153 (1–4), 95–102. <https://doi.org/10.1007/s10661-008-0344-7>
- Fowler, S.W., 2018. The fate and effects of petroleum hydrocarbons in marine ecosystems. *Marine Pollution Bulletin* 135, 102–115. <https://doi.org/10.1016/j.marpolbul.2018.07.010>
- Nwabueze, E.O., 2011. Levels of petroleum hydrocarbons and some heavy metals in tissues of *Tympanotonus fuscatus* periwinkles from Warri River of Niger Delta Area of Nigeria. University of Port Harcourt (MSc Dissertation).
- Singh, P., Kumar, A., Agarwal, S., Mahapatra, M., 2024. Bioindicators for aquatic pollution monitoring: Current status and future perspectives. *Environmental Science and Pollution Research* 31 (3), 4567–4585. <https://doi.org/10.1007/s11356-023-30501-5>
- Spacie, A., McCarty, L.S., Rand, G.M., 2020. Bioaccumulation and toxicity of petroleum hydrocarbons in aquatic organisms. *Environmental Toxicology and Chemistry* 39 (8), 1482–1497. <https://doi.org/10.1002/etc.4739>
- Springer Nature, 2026. Biomonitoring of total petroleum hydrocarbons contamination in coastal sediments and accumulation in *Tympanotonus fuscatus* var. *radula* from Rivers State, Nigeria. *Emerging Contaminants* 9, 15.
- USEPA, 1989. Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part A). EPA/540/1-89/002. United States Environmental Protection Agency, Washington, DC.
- USEPA, 2000. Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000). EPA-822-B-00-004. United States Environmental Protection Agency, Washington, DC.
- Wood Mackenzie, 2024. OML 118 (Bonga) Upstream Oil and Gas Report. Wood Mackenzie Ltd, Edinburgh.
- Zabbey, N., Sam, K., Onyebuchi, A.T., 2017. Impacts of oil spills on the Niger Delta ecosystem: A review. *Environmental Reviews* 25 (4), 396–407. <https://doi.org/10.1139/er-2016-0108>
- Adesakin, T. A., et al. (2023). Bioaccumulation of heavy metals in *Red snipper (Lutjanus spp.)* from selected creeks in the Niger Delta. *Environmental Monitoring and Assessment*, 195(2), 245.
- Akinwumiju, A. S., et al. (2020). Oil spill incidents in the Niger Delta: A review of causes,

Corresponding author: Adams Oladimeji Peter

✉ oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.



- impacts and mitigation. *Environmental Science and Pollution Research*, 27(15), 17842–17860.
- Alzahrani, D. A., & Rajendran, S. (2019). Petroleum hydrocarbon pollution in coastal environments: A review. *Marine Pollution Bulletin*, 149, 110612.
- Canadian Council of Ministers of the Environment (CCME). (2014). *Canadian sediment quality guidelines for the protection of aquatic life*. CCME.
- Chinedu, E., & Chukwuemeka, C. K. (2018). Oil spillage and heavy metals toxicity risk in the Niger Delta, Nigeria. *Journal of Health and Pollution*, 8(19), 180905.
- Chris, D. I., et al. (2024). Biomonitoring potential of *Red snapper (lutjanus spp)* in crude oil polluted creeks. *Journal of Applied Sciences and Environmental Management*, 28(1), 87–94.
- Dada, O. A., et al. (2018). Seasonal variation of total hydrocarbon content in sediments of Lagos Lagoon, Nigeria. *Journal of Applied Sciences and Environmental Management*, 22(8), 1249–1254.
- Department of Petroleum Resources (DPR). (2018). *Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN)*, 3rd Edition. DPR.
- Dippong, T., & Resz, M. A. (2024). Heavy metal pollution assessment in aquatic ecosystems: A review of indices and approaches. *Water*, 16(2), 234.
- Dippong, T., et al. (2022). Heavy metal contamination assessment in surface sediments from the Someş Mic River, Romania. *Water*, 14(9), 1456.
- Dippong, T., et al. (2023). Water quality and pollution indices as tools for environmental monitoring. *Environmental Science and Pollution Research*, 30(12), 32567–32583.
- Elijah, T. (2022). Hydrocarbon contamination in Niger Delta: A review of sources, impacts and remediation. *Journal of Environmental Management*, 299, 113641.
- Elum, Z. A., et al. (2016). Oil extraction and its impact on the Niger Delta region of Nigeria. *Environmental Science and Pollution Research*, 23(15), 14756–14770.
- Essien, J. P., et al. (2009). *Chromatium* species: An emerging bioindicator of crude oil pollution of tidal mud flats in the Niger Delta mangrove ecosystem, Nigeria. *Environmental Monitoring and Assessment*, 153(1-4), 95–102.
- Fowler, S. W. (2018). The fate and effects of petroleum hydrocarbons in marine ecosystems. *Marine Pollution Bulletin*, 135, 102–115.
- Ibanga, I. S., et al. (2019). Benthic macroinvertebrates as bioindicators of water quality in the Niger Delta. *Journal of Environmental Biology*, 40(4), 875–882.
- Ite, A. E., et al. (2016). Petroleum hydrocarbons contamination of surface water and groundwater in the Niger Delta region of Nigeria. *Journal of Environmental Protection*, 7(6), 861–883.
- Jemimah, O. O., & Ike, C. N. (2015). Health implications of hydrocarbon contamination in seafood from the Niger Delta. *Journal of Environmental and Public Health*, 2015, 851351.
- Kuppusamy, S., et al. (2020). Total petroleum hydrocarbons in environmental matrices: A review of analytical methods and global levels. *TrAC Trends in Analytical Chemistry*, 125, 115845.
- Lukhabi, D. K., et al. (2024). Benthic macroinvertebrates as indicators of aquatic ecosystem health: A global review. *Ecological Indicators*, 158, 111423.
- Mahato, M. K., et al. (2024). Heavy metal pollution indices and their application in environmental assessment. *Environmental Chemistry and Ecotoxicology*, 6, 45–58.
- Maletić, S. P., et al. (2019). Petroleum hydrocarbon biodegradation in contaminated soil and water. *Journal of the Serbian Chemical Society*, 84(5), 471–495.

Corresponding author: Adams Oladimeji Peter

✉ oaopeter.pg@atbu.edu.ng

Environmental Standard Node, Sustainable Procurement, Environmental and Social Standards Project, Centre of Excellence Abubakar Tafawa Balewa University Bauchi, Nigeria

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved.